PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53(c).

DOCKET NUMBER: C1104-7139.00
Express Mail Label No. EV308900581US
Date of Deposit: July 15, 2004

INVENTOR(S)/APPLICANT(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Frederick	Morgan	Quincy, MA
George	Mueller	Boston, MA
Kevin	Dowling	Westford, MA
Ihor	Lys	Milton, MA
Charles	Cella	Pembroke, MA
Edward	Nortrup	Stoneham, MA

TITLE OF THE INVENTION (500 characters max)
LED PACKAGE METHODS AND SYSTEMS

CORRESPONDENCE ADDRESS
CUSTOMER NUMBER: 37462

ENCLOSED APPLICATION PARTS *(check all that apply)*

[X] Specification *Number of Pages* 151

[X] Drawing(s) *Number of Sheets* 102

[ ] Application Data Sheet, See 37 CFR 1.76

[X] Return receipt postcard

[ ] Other (specify) ____________

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[X] No

[ ] Yes, the name of the U.S. Government Agency and the Government Contract Number are:

METHOD OF PAYMENT *(check all that apply)*

[X] A check is enclosed to cover the Provisional Filing Fees.
The Commissioner is hereby authorized to charge any additional fees or credit overpayment to Deposit Account 50/2762. A duplicate of this sheet is enclosed.

[ ] Small Entity Status is claimed.

PROVISIONAL FILING FEE AMOUNT $ 160.00

July 15, 2004
Date

Respectfully submitted,

Joseph Teja, Jr., Reg. No. 45,157
Telephone No.: 617-395-7000

C1104-7139.00
746156.1

Express Mail Label No.: EV 308900581 US
Date of Deposit: July 15, 2004

LED PACKAGE METHODS AND SYSTEMS

Background

LED packages have been developed that include an LED die and a submount that includes a diode, such as an ESD diode. However, current LED packages require manufacturers to develop and implement many separate electronic components in order to power the LED dies and to control the light coming from the LED dies. A need exists to simplify the challenges of powering and controlling LED packages.

Summary

Methods and systems are provided herein for LED modules that include an LED die integrated in an LED package with a submount that includes an electronic component for controlling the light emitted by the LED die. The electronic component integrated in the submount may include drive hardware, a network interface, memory, a processor, a switch-mode power supply, a power facility, or another type of electronic component.

In one aspect, there is disclosed herein a light source including at least one LED die including an LED, and a package for the LED die, the package including a submount, wherein the submount incorporates an electronic component for controlling the LED, wherein the electronic component facilitates control of at least one of the intensity and the apparent intensity of the LED die.

In another aspect, there is disclosed herein is a method for providing a light source including providing at least one LED in an LED die, and packaging the LED die with a submount, wherein the submount incorporates an electronic component for controlling the LED, wherein the electronic component facilitates control of at least one of the intensity and the apparent intensity of the LED die.

In still another aspect, there is disclosed herein a lighting system including a plurality of light sources including at least one LED in an LED die, the LED die packaged with a submount, wherein the submount incorporates an electronic component

for controlling the LED, wherein the electronic component facilitates control of at least one of the intensity and the apparent intensity of the LED die among at least three distinct levels of intensity.

The intensity or apparent intensity of the LED die may be controlled by the electronic component among at least three distinct levels of intensity.

In these various aspects, The LED package may include components selected from the group consisting of a an optical facility, a lens, an LED die mounted in a reflector cup, a silicone filling, a wire bond between the LED and the edge of the reflector cup, a submount, a diode in the submount, and a plurality of isolated leads for electrically connecting the LED die to a power source. The LED package may include an LED die mounted in a reflector cup and surrounded by an injection molding. The LED package may include an LED die and submount mounted in a reflector cup and surrounded by a plastic package. The LED package may be created by a mask. The LED package may have a substrate, wherein the substrate is selected from the group consisting of a metal core substrate, a ceramic substrate, a ceramic on metal substrate, an FR4 substrate, a sapphire substrate, an silicon on sapphire substrate, and a silicon carbide substrate.

In these various aspects, at one of the levels of intensity the LED die may be in an off condition. The package may include a reflector. The package may include an electro-static discharge protection diode.

In various aspects, the electronic component may be mounted on one or more submounts of the package. The electronic component may include a current regulator for allowing the module to take a 12V DC signal. The electronic component may include a circuit for taking a 12V AC signal directly. The electronic component may include at least one of a bridge rectifier, a capacitor, and a current regulator.

In various aspects, the LED package may include an optical facility.

In various aspects, the electronic component may include a circuit for taking an AC signal with voltage in a range from 100V to 240V. The electronic component may include a switch mode power supply and a current regulator. The electronic component may include a circuit. The electronic component may include a dimming circuit. The electronic component may be responsive to power-cycle events. The electronic component may include a data interface. The data interface may be configured to receive a signal selected from the group consisting of a DMX signal, a DALI signal, an Ethernet signal, a TCP/IP protocol signal, an HTTP protocol signal, an XML or other mark-up language instruction, a script, an 802.11 or other wireless signal, a cellular or radio-frequency signal, an infrared signal, or a Bluetooth signal. The electronic component may include firmware. The firmware may include an XML parser. The firmware may include firmware for responding to a signal selected from the group consisting of a DMX signal, a DALI signal, an Ethernet signal, a TCP/IP protocol signal, an HTTP protocol signal, an 802.11 signal, a cellular telephony signal, a radio-frequency signal, an infrared signal, or a Bluetooth signal.

In various aspects, the electronic component may include an application specific integrated circuit. The application specific integrated circuit may respond to signals according to a serial addressing protocol. The electronic component may include a processor. The processor may control a signal by pulse-width-modulation. The processor may control a signal by pulse-amplitude-modulation. The processor may select between a pulse-width-modulation mode and a pulse-amplitude-modulation mode. The processor may provide calibration for the light source. The processor may respond to a sensor, such as in a sensor-feedback loop.

In various aspects, the electronic component may include a voltage regulator. The electronic component may include a power-factor-control circuit. The electronic component may include an inductive loop drive circuit. The electronic component may include a feed-forward drive circuit. The electronic component may respond to a combined power/data signal.

In various aspects, the electronic component may provide an address for the light source. The electronic component may be a signal source for a signal including at least one of a DMX signal, a DALI signal, an Ethernet signal, a TCP/IP protocol signal, an HTTP protocol signal, an 802.11 signal, a cellular telephony signal, a radio-frequency signal, an infrared signal, or a Bluetooth signal.

In various aspects, the electronic component may include a temperature sensor. The electronic component may include a timing facility. The electronic component may include a drive circuit adapted to receive an arbitrary voltage. The electronic component may include a microcontroller. The electronic component may include a drive circuit adapted to receive high voltage. The drive circuit may include a power-factor-corrected drive circuit.

In various aspects, the electronic component may include a data storage facility. The data storage facility may include memory. The data storage facility may include a lookup table for storing values for a control signal for the LED. The data storage facility may store programs for controlling the light source. The data storage facility may store programs for responding to control signals from a signal source. The data storage facility may store a program for controlling power to the LED die based on the anticipated requirements of the installation of the light source. The data storage facility may include an erasable programmable read-only memory.

In various aspects, the electronic component may include a photosensor. The electronic component may include a digital-to-analog converter. The electronic component may include an analog-to-digital converter. The electronic component may include a power facility. The electronic component may include a wireless control facility. The electronic component may include a bridge rectifier. The electronic component may include a boost converter. The electronic component may include a boost regulator. The component may include an analog dimming input. The electronic component may include a resistor for assisting in identification of the light source. The

electronic component may include a temperature sensor and a facility for controlling the LED in response to a thermal condition.

In various aspects, the light sources described above may include a facility for connecting the light source to a conductive element. The conductive element may include a linear conductive element. The conductive element may include a rail.

The light source may be for a boat light. The light source may be for an MR-type fixture. The light source may be for a reading light. The LED die may include a high-power LED die. The LED die may include a 5W or greater LED die. The light source may be for a camera flash. The light source may include an external resistor for adjusting a voltage input to the light source.

In various embodiments, the light source may include an optical facility including at least one of a lens, a filter, a diffuser, a reflector, a phosphorescent material, or a luminescent material. The optical facility may include at least one of a Bragg cell, a holographic film, a digital mirror, a spinning mirror, a light pipe, a color mixing system, or a microlens array.

In certain aspects, a light source includes at least one LED die including an LED, and a package for the LED die, the LED package including a submount, wherein the submount incorporates an electronic component for controlling the LED, wherein the electronic component facilitates control of at least one of the intensity and the apparent intensity of the LED die.

The LED package may include a thermal facility for cooling at least one of the LED die and the submount. The thermal facility may be selected from the group consisting of a Peltier effect device, a fluid cooling facility, a potting facility, a thermally conductive plate, a gap pad, a micro-machine, a MEMs device, and a fan.

The light source may further include an external electrical component for the package, wherein the external component is selected from the group consisting of a capacitor, a resistor, and an inductor. The external component may be a capacitor for energy storage and wherein the submount includes a dimmer-compatible circuit. The external component may be a resistor to set a voltage level of the input signal to the LED package. The external component may be a capacitor for bulk energy storage. The external component may be an inductor.

The light source may include a reflective cup, the reflective cup serving as an inductor for the LED package. At least one of the submount and the LED may be fabricated from a heat-tolerant material. The heat-tolerant material may be silicon carbide. The light source may include a memory facility such as an SRAM.

The electronic component may be a buck converter, a flyback converter, or a current regulator.

The LED package may be compression molded or plastic molded. The LED package may include a material such as a metal, a ceramic, an epoxy, a plastic, a glass, a polymer, and/or a compound.

The LED package may be used as an indicator. The indicator may indicate a sensed condition. The condition may include acceleration, pressure, temperature, time, humidity, light, a fault condition, proximity, and/or a chemical condition. The indicator may display a state of a device, such as a sensor.

The electronic component may include a MEMS device. The MEMS device may include a pressure transducer, an active cooling device, a chemical detector, a gyro, an accelerometer, a timer, and/or an oscillator. The electronic component may include a Peltier effect device.

The LED package may be used as a component for a display. The display may include a graphics display, a monitor, a video display, and an animation display. The LED package may include an input/output facility. The light source may include a photovoltaic energy source.

The LED package may be used in a road barrier. The LED package may be used in a cellular phone. The LED package may operate directly from the power source for the cell phone. The LED package may be used in an automobile, where the LED package may operate directly on an electrical bus for the automobile or on power from a battery, such as a 1.5 Volt battery. The LED package may be used in connection with a gaming device, an elevator, an automation system for a factory, and/or a traffic signal. The LED package may be used in a photographic flash.

It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein.

The following patents and patent applications are hereby incorporated herein by reference:

U.S. Patent No. 6,016,038, issued January 18, 2000, entitled "Multicolored LED Lighting Method and Apparatus;"

U.S. Patent No. 6,211,626, issued April 3, 2001 to Lys et al, entitled "Illumination Components,"

U.S. Patent No. 6,608,453, issued August 19, 2003, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. Patent No. 6,548,967, issued April 15, 2003, entitled "Universal Lighting Network Methods and Systems;"

U.S. Patent Application Serial No. 09/886,958, filed June 21, 2001, entitled Method and Apparatus for Controlling a Lighting System in Response to an Audio Input;"

U.S. Patent Application Serial No. 10/078,221, filed February 19, 2002, entitled "Systems and Methods for Programming Illumination Devices;"

U.S. Patent Application Serial No. 09/344,699, filed June 25, 1999, entitled "Method for Software Driven Generation of Multiple Simultaneous High Speed Pulse Width Modulated Signals;"

U.S. Patent Application Serial No. 09/805,368, filed March 13, 2001, entitled "Light-Emitting Diode Based Products;"

U.S. Patent Application Serial No. 09/716,819, filed November 20, 2000, entitled "Systems and Methods for Generating and Modulating Illumination Conditions;"

U.S. Patent Application Serial No. 09/675,419, filed September 29, 2000, entitled "Systems and Methods for Calibrating Light Output by Light-Emitting Diodes;"

U.S. Patent Application Serial No. 09/870,418, filed May 30, 2001, entitled "A Method and Apparatus for Authoring and Playing Back Lighting Sequences;"

U.S. Patent Application Serial No. 10/045,604, filed March 27, 2003, entitled "Systems and Methods for Digital Entertainment;"

U.S. Patent Application Serial No. 10/045,629, filed October 25, 2001, entitled "Methods and Apparatus for Controlling Illumination;"

U.S. Patent Application Serial No. 09/989,677, filed November 20, 2001, entitled "Information Systems;"

U.S. Patent Application Serial No. 10/158,579, filed May 30, 2002, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. Patent Application Serial No. 10/163,085, filed June 5, 2002, entitled "Systems and Methods for Controlling Programmable Lighting Systems;"

U.S. Patent Application Serial No. 10/174,499, filed June 17, 2002, entitled "Systems and Methods for Controlling Illumination Sources;"

U.S. Patent Application Serial No. 10/245,788, filed September 17, 2002, entitled "Methods and Apparatus for Generating and Modulating White Light Illumination Conditions;"

U.S. Patent Application Serial No. 10/245,786, filed September 17, 2002, entitled "Light Emitting Diode Based Products;"

U.S. Patent Application Serial No. 10/325,635, filed December 19, 2002, entitled "Controlled Lighting Methods and Apparatus;"

U.S. Patent Application Serial No. 10/360,594, filed February 6, 2003, entitled "Controlled Lighting Methods and Apparatus;"

U.S. Patent Application Serial No. 10/435,687, filed May 9, 2003, entitled "Methods and Apparatus for Providing Power to Lighting Devices;"

U.S. Patent Application Serial No. 10/828,933, filed April 21, 2004, entitled "Tile Lighting Methods and Systems;"

U.S. Patent Application Serial No. 60/553,318, filed March 15, 2004, entitled "Power Control Methods and Apparatus;" and

U.S. Patent Application Serial No. 60/558,400, filed March 31, 2004, entitled "Methods and Systems for Providing Lighting Components."

Brief Description of the Figures

The foregoing and other objects and advantages of the invention will be appreciated more fully from the following further description thereof, with reference to the accompanying drawings, wherein:

Fig. 1 depicts a configuration for a controlled lighting system.

Fig. 2 is a schematic diagram with elements for a lighting system.

Fig. 3 depicts configurations of light sources that can be used in a lighting system.

Fig. 4 depicts an optical facility for a lighting system.

Fig. 5 depicts diffusers that can serve as optical facilities.

Fig. 6 depicts optical facilities.

Fig. 7 depicts optical facilities for lighting systems.

Fig. 8 depicts a tile light housing for a lighting system.

Fig. 9 depicts housings for architectural lighting systems.

Fig. 10 depicts specialized housings for lighting systems.

Fig. 11 depicts housings for lighting systems.

Fig. 12 depicts a signage housing for a lighting system.

Fig. 13 depicts a housing for a retrofit lighting unit.

Figs. 14a and 14b depict housings for a linear fixture.

Fig. 15 depicts a power circuit for a lighting system with power factor correction.

Fig. 16 depicts another embodiment of a power factor correction power system.

Fig. 17 depicts another embodiment of a power system for a lighting system that includes power factor correction.

Fig. 18 depicts drive hardware for a lighting system.

Fig. 19 depicts thermal facilities for a lighting system.

Fig. 20 depicts mechanical interfaces for lighting systems.

Fig. 21 depicts additional mechanical interfaces for lighting systems.

Fig.22 depicts additional mechanical interfaces for a lighting system.

Fig. 23 depicts a mechanical interface for connecting two linear lighting units.

Fig. 24 depicts drive hardware for a lighting system.

Fig. 25 depicts methods for driving lighting systems.

Fig. 26 depicts a chromaticity diagram for a lighting system.

Fig. 27 depicts a configuration for a light system manager.

Fig. 28 depicts a configuration for a networked lighting system.

Fig. 29 depicts an XML parser environment for a lighting system.

Fig. 30 depicts a network with a central control facility for a lighting system.

Fig. 31 depicts network topologies for lighting systems.

Fig. 32 depicts a physical data interface for a lighting system with a communication port.

Fig. 33 depicts physical data interfaces for lighting systems.

Fig. 34 depicts user interfaces for lighting systems.

Fig. 35 depicts additional user interfaces for lighting systems.

Fig. 36 depicts a keypad user interface.

Fig. 37 depicts a configuration file for mapping locations of lighting systems.

Fig. 38 depicts a binary tree for a method of addressing lighting units.

Fig. 39 depicts a flow diagram for mapping locations of lighting units.

Fig. 40 depicts steps for mapping lighting units.

Fig. 41 depicts a method for mapping and grouping lighting systems for purposes of authoring shows.

Fig. 42 depicts a graphical user interface for authoring lighting shows.

Fig. 43 depicts a user interface screen for an authoring facility.

Fig. 44 depicts effects and meta effects for a lighting show.

Fig. 45 depicts steps for converting an animation into a set of lighting control signals.

Fig. 46 depicts steps for associating lighting control signals with other object-oriented programs.

Fig. 47 depicts parameters for effects.

Fig. 48 depicts effects that can be created using lighting systems.

Fig. 49 depicts additional effects.

Fig. 50 depicts additional effects.

Fig. 51 depicts environments for lighting systems.

Fig. 52 depicts additional environments for lighting systems.

Fig. 53 depicts additional environments for lighting systems.

Fig. 54 depicts additional environments for lighting systems.

Fig. 55 depicts additional environments for lighting systems.

Fig. 56 shows a cross-section of an LED module used as a light source.

Fig. 57 shows an LED module with electro-static discharge protection.

Fig. 58 shows a cross-section of an LED module constructed with injection molding.

Fig. 59 shows a cross-section of an LED module with components mounted in a cup of a reflector.

Fig. 60 shows an LED module having a group of LED dies in a package with a current regulator.

Fig. 61 shows an LED package adapted to receive an AC signal.

Fig. 62 shows an LED package adapted to receive either an AC signal or a DC signal.

Fig. 63 shows an LED package including circuitry to control LED intensity.

Fig. 64 shows an LED package including circuitry to respond to power signal events.

Fig. 65 shows an LED package including a data interface.

Fig. 66 shows an LED package including an application specific integrated circuit.

Fig. 67 shows an LED package including a processor.

Fig. 68 shows an LED package including a sensor input.

Fig. 69 shows an LED package including a power factor control circuit.

Fig. 70 shows an LED package including an inductive loop drive circuit.

Fig. 71 shows an LED package including a feed-forward drive circuit.

Fig. 72 shows an LED package including a power/data facility.

Fig. 73 shows an LED package including a timing facility.

Fig. 74 shows an LED package including a high-voltage input.

Fig. 75 shows an LED package including a data facility.

Fig. 76 shows an LED package including a digital-to-analog converter.

Fig. 77 shows an LED package including a bridge rectifier.

Fig. 78 shows an LED package including a boost converter.

Fig. 79 shows an LED package including a boost regulator.

Fig. 80 shows an LED package including multiple components and multiple inputs.

Fig. 81 shows an LED package including a component for attaching to an external conductor.

Fig. 82 shows an LED package including a thermal facility.

Fig. 83 shows an LED package with external components.

Fig. 84 shows an LED package with an external capacitor.

Fig. 85 shows an LED package with an external resistor.

Fig. 86 shows an LED package with an external inductor.

Fig. 87 shows an LED package with an input/output facility.

Fig. 88 shows an LED package including a converter.

Fig. 89 shows an LED package including a converter.

Fig. 90 shows an LED package including a current regulator.

Fig. 91 shows an LED package including a MEMS device.

Fig. 92 shows an LED package including a MEMS cooling element.

Fig. 93 shows an LED package including a MEMS pressure transducer.

Fig. 94 shows an LED package including a chemical detector.

Fig. 95 shows an LED package including a gyro.

Fig. 96 shows an LED package including an accelerometer.

Fig. 97 shows an LED package including an oscillator.

Fig. 98 shows an LED package including a Peltier effect device.

Fig. 99 shows an LED package used in a cellular phone.

Fig. 100 shows an LED package used in an automobile.

Fig. 101 shows an LED package used in a road barrier.

Detailed Description

Referring to Fig. 1, in a lighting system 100 a lighting unit 102 is controlled by a control facility 3500. In embodiments, the control facility 3500 controls the intensity, color, saturation, color temperature, on-off state, brightness, or other feature of light that is produced by the lighting unit 102. The lighting unit 102 can draw power from a power facility 1800. The lighting unit 102 can include a light source 300, which in embodiments is a solid-state light source, such as a semiconductor-based light source, such as light emitting diode, or LED.

Referring to Fig. 2, the system 100 can be a solid-state lighting system and can include the lighting unit 102 as well as a wide variety of optional control facilities 3500.

In embodiments, the system 100 may include an electrical facility 202 for powering and controlling electrical input to the light sources 300, which may include drive hardware 3802, such as circuits and similar elements, and the power facility 1800.

In embodiments the system can include a mechanical interface 3200 that allows the lighting unit 102 to mechanically connect to other portions of the system 100, or to

external components, products, lighting units, housings, systems, hardware, or other items.

The lighting unit 102 may have a primary optical facility 1700, such as a lens, mirror, or other optical facility for shaping beams of light that exit the light source, such as photons exiting the semiconductor in an LED package

The system 100 may include an optional secondary optical facility 400, which may diffuse, spread, focus, filter, diffract, reflect, guide or otherwise affect light coming from a light source 300. The secondary optical facility 400 may include one or many elements.

In embodiments, the light sources 300 may be disposed on a support structure, such as a board 204. The board 204 may be a circuit board or similar facility suitable for holding light sources 300 as well as electrical components, such as components used in the electrical facility 202.

In embodiments the system 100 may include a thermal facility 2500, such as a heat-conductive plate, metal plate, gap pad, liquid heat-conducting material, potting facility, fan, vent, or other facility for removing heat from the light sources 300.

The system 100 may optionally include a housing 800, which in embodiments may hold the board 204, the electrical facility 202, the mechanical interface 3200, and the thermal facility 2500. In some embodiments, no housing 800 is present.

In embodiments the system 100 is a standalone system with an on-board control facility 3500. The system 100 can include a processor 3600 for processing data to accept control instructions and to control the drive hardware 3802.

In embodiments the system 100 can respond to control of a user interface 4908, which may provide control directly to the lighting unit 102, such as through a switch,

dial, button, dipswitch, slide mechanism, or similar facility or may provide control through another facility, such as a network interface 4902, a light system manager 5000, or other facility.

The system 100 can include a data storage facility 3700, such as memory. In a standalone embodiment the data storage facility 3700 may be memory, such as random access memory. In other embodiments the data storage facility 3700 may include any other facility for storing and retrieving data.

The system 100 can produce effects 9200, such as illumination effects 9300 that illuminate a subject 9900 and direct view effects 9400 where the viewer is intended to view the light sources 300 or the secondary optical facility 400 directly, in contrast to viewing the illumination produced by the light sources 300, as in illumination effects 9300. Effects can be static and dynamic, including changes in color, color-temperature, intensity, hue, saturation and other features of the light produced by the light sources 300. Effects from lighting units 102 can be coordinated with effects from other systems, including other lighting units 102.

The system 100 can be disposed in a wide variety of environments 9600, where effects 9200 interact with aspects of the environments 9600, such as subjects 9900, objects, features, materials, systems, colors or other characteristics of the environments. Environments 9600 can include interior and exterior environments, architectural and entertainment environments, underwater environments, commercial environment, industrial environments, recreational environments, home environments, transportation environments and many others.

Subjects 9900 can include a wide range of subjects 9900, ranging from objects such as walls, floors and ceilings to alcoves, pools, spas, fountains, curtains, people, signs, logos, buildings, rooms, objects of art and photographic subjects, among many others.

While embodiments of a control facility 3500 may be as simple as a single processor 3600, data storage facility 3700 and drive hardware 3802, in other embodiments more complex control facilities 3500 are provided. Control facilities may include more complex drive facilities 3800, including various forms of drive hardware 3802, such as switches, current sinks, voltage regulators, and complex circuits, as well as various methods of driving 4300, including modulation techniques such as pulse-width-modulation, pulse-amplitude-modulation, combined modulation techniques, table-based modulation techniques, analog modulation techniques, and constant current techniques. In embodiments a control facility 3500 may include a combined power/data protocol 4800 for controlling light sources 300 in response to data delivered over power lines.

A control facility 3500 may include a control interface 4900, which may include a physical interface 4904 for delivering data to the lighting unit 102. The control interface 4900 may also include a computer facility, such as a light system manager 5000 for managing the delivery of control signals, such as for complex shows and effects 9200 to lighting units 102, including large numbers of lighting units 102 deployed in complex geometric configurations over large distances.

The control interface 4900 may include a network interface 4902, such as for handling network signals according to any desired network protocol, such as DMX, Ethernet, TCP/IP, DALI, 802.11 and other wireless protocols, and linear addressing protocols, among many others. In embodiments the network interface 4902 may support multiple protocols for the same lighting unit 102.

In embodiments involving complex control, the physical data interface 4904 may include suitable hardware for handling data transmissions, such as USB ports, serial ports, Ethernet facilities, wires, routers, switches, hubs, access points, buses, multi-function ports, intelligent sockets, intelligent cables, flash and USB memory devices, file players, and other facilities for handling data transfers.

In embodiments the control facility 3500 may include an addressing facility 6600, such as for providing an identifier or address to one or more lighting units 102. Many kinds of addressing facility 6600 may be used, including facilities for providing network addresses, dipswitches, bar codes, sensors, cameras, and many others.

In embodiments the control facility 3500 may include an authoring facility 7400 for authoring effects 9200, including complex shows and static and dynamic effects. The authoring facility 7400 may be associated with the light system manager 5000, such as to facilitate delivery of control signals for complex shows and effects over a network interface 4900 to one or more lighting units 102. The authoring facility 7400 may include a geometric authoring facility, an interface for designing light shows, an object-oriented authoring facility, an animation facility, or any of a variety of other facilities for authoring shows and effects.

In embodiments the control facility 3500 may take input from a signal source 8400, such as a sensor 8402, an information source, a light system manager 5000, a user interface 4908, a network interface 4900, a physical data interface 4904, an external system 8800, or any other source capable of producing a signal.

In embodiments the control facility 3500 may respond to an external system 8800. The external system 8800 may be a computer system, an automation system, a security system, an entertainment system, an audio system, a video system, a personal computer, a laptop computer, a handheld computer, or any of a wide variety of other systems that are capable of generating control signals.

Referring to Fig. 3, the lighting unit 102 may be any kind of lighting unit 102 that is capable of responding to control, but in embodiments the lighting unit 102 includes a light source 300 that is a solid-state light source, such as a semiconductor-based light source, such as a light emitting diode, or LED. Lighting units 102 can include LEDs that produce a single color or wavelength of light, or LEDs that produce different colors or wavelengths, including red, green, blue, white, orange, amber, ultraviolet, infrared,

purple or any other wavelength of light. Lighting units 102 can include other light sources, such as organic LEDS, or OLEDs, light emitting polymers, crystallo-luminescent lighting units, lighting units that employ phosphors, luminescent polymers and other sources. In other embodiments, lighting units 102 may include incandescent sources, halogen sources, metal halide sources, fluorescent sources, compact fluorescent sources and others.

Referring still to Fig. 3, the sources 300 can be point sources or can be arranged in many different configurations 302, such as a linear configuration 306, a circular configuration 308, an oval configuration 304, a curvilinear configuration, or any other geometric configuration, including two-dimensional and three-dimensional configurations. The sources 300 can also be mixed, including sources 300 of varying wavelength, intensity, power, quality, light output, efficiency, efficacy or other characteristics. In embodiments sources 300 for different lighting units 102 are consistently mixed to provide consistent light output for different lighting units 102. In embodiments the sources are mixed 300 to allow light of different colors or color temperatures, including color temperatures of white. Various mixtures of sources 300 can produce substantially white light, such as mixtures of red, green and blue LEDs, single white sources 300, two white sources of varying characteristics, three white sources of varying characteristics, or four or more white sources of varying characteristics. One or more white source can be mixed with, for example, an amber or red source to provide a warm white light or with a blue source to produce a cool white light.

Sources 300 may be constructed and arranged to produce a wide range of variable color radiation. For example, the source 300 may be particularly arranged such that the processor-controlled variable intensity light generated by two or more of the light sources combines to produce a mixed colored light (including essentially white light having a variety of color temperatures). In particular, the color (or color temperature) of the mixed colored light may be varied by varying one or more of the respective intensities of the light sources or the apparent intensities, such as using a duty cycle in a

pulse width modulation technique. Combinations of LEDs with other mechanisms that affect light characteristics, such as phosphors, are also encompassed herein.

Any combination of LED colors can produce a gamut of colors, whether the LEDs are red, green, blue, amber, white, orange, UV, or other colors. The various embodiments described throughout this specification encompass all possible combinations of LEDs in lighting units 102, so that light of varying color, intensity, saturation and color temperature can be produced on demand under control of a control facility 3500.

Although mixtures of red, green and blue have been proposed for light due to their ability to create a wide gamut of additively mixed colors, the general color quality or color rendering capability of such systems are not ideal for all applications. This is primarily due to the narrow bandwidth of current red, green and blue emitters. However, wider band sources do make possible good color rendering, as measured, for example, by the standard CRI index. In some cases this may require LED spectral outputs that are not currently available. However, it is known that wider-band sources of light will become available, and such wider-band sources are encompassed as sources for lighting units 102 described herein..

Additionally, the addition of white LEDs (typically produced through a blue or UV LED plus a phosphor mechanism) does give a 'better' white, but it still can be limiting in the color temperature that is controllable or selectable from such sources.

The addition of white to a red, green and blue mixture may not increase the gamut of available colors, but it can add a broader-band source to the mixture. The addition of an amber source to this mixture can improve the color still further by 'filling in' the gamut as well.

Combinations of light sources 300 can help fill in the visible spectrum to faithfully reproduce desirable spectrums of lights. These include broad daylight

equivalents or more discrete waveforms corresponding to other light sources or desirable light properties. Desirable properties include the ability to remove pieces of the spectrum for reasons that may include environments where certain wavelengths are absorbed or attenuated. Water, for example tends to absorb and attenuate most non-blue and non-green colors of light, so underwater applications may benefit from lights that combine blue and green sources 300.

Amber and white light sources can offer a color temperature selectable white source, wherein the color temperature of generated light can be selected along the black body curve by a line joining the chromaticity coordinates of the two sources. The color temperature selection is useful for specifying particular color temperature values for the lighting source.

Orange is another color whose spectral properties in combination with a white LED-based light source can be used to provide a controllable color temperature light from a lighting unit 102.

As used herein, "Color Kinetics" means Color Kinetics Incorporated a Delaware corporation with headquarters in Boston, Massachusetts.

As used herein for purposes of the present disclosure, the term "LED" should be understood to include any light emitting diode or other type of carrier injection / junction-based system that is capable of generating radiation in response to an electric signal. Thus, the term LED includes, but is not limited to, various semiconductor-based structures that emit light in response to current, light emitting polymers, light-emitting strips, electro-luminescent strips, and the like.

In particular, the term LED refers to light emitting diodes of all types (including semi-conductor and organic light emitting diodes) that may be configured to generate radiation in one or more of the infrared spectrum, ultraviolet spectrum, and various portions of the visible spectrum (generally including radiation wavelengths from

approximately 400 nanometers to approximately 700 nanometers). Some examples of LEDs include, but are not limited to, various types of infrared LEDs, ultraviolet LEDs, red LEDs, blue LEDs, green LEDs, yellow LEDs, amber LEDs, orange LEDs, and white LEDs (discussed further below). It also should be appreciated that LEDs may be configured to generate radiation having various bandwidths for a given spectrum (e.g., narrow bandwidth, broad bandwidth).

For example, one implementation of an LED configured to generate essentially white light (e.g., a white LED) may include a number of dies which respectively emit different spectrums of luminescence that, in combination, mix to form essentially white light. In another implementation, a white light LED may be associated with a phosphor material that converts luminescence having a first spectrum to a different second spectrum. In one example of this implementation, luminescence having a relatively short wavelength and narrow bandwidth spectrum "pumps" the phosphor material, which in turn radiates longer wavelength radiation having a somewhat broader spectrum.

It should also be understood that the term LED does not limit the physical and/or electrical package type of an LED. For example, as discussed above, an LED may refer to a single light emitting device having multiple dies that are configured to respectively emit different spectrums of radiation (e.g., that may or may not be individually controllable). Also, an LED may be associated with a phosphor that is considered as an integral part of the LED (e.g., some types of white LEDs). In general, the term LED may refer to packaged LEDs, non-packaged LEDs, surface mount LEDs, chip-on-board LEDs, radial package LEDs, power package LEDs, LEDs including some type of encasement and/or optical element (e.g., a diffusing lens), etc.

The term "light source" should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources as defined above, incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of luminescent sources, electro-

luminescent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g., gaseous discharge sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources , sonoluminescent sources, radioluminescent sources, and luminescent polymers.

A given light source may be configured to generate electromagnetic radiation within the visible spectrum, outside the visible spectrum, or a combination of both. Hence, the terms "light" and "radiation" are used interchangeably herein. Additionally, a light source may include as an integral component one or more filters (e.g., color filters), lenses, or other optical components. Also, it should be understood that light sources may be configured for a variety of applications, including, but not limited to, indication and/or illumination. An "illumination source" is a light source that is particularly configured to generate radiation having a sufficient intensity to effectively illuminate an interior or exterior space.

The term "spectrum" should be understood to refer to any one or more frequencies (or wavelengths) of radiation produced by one or more light sources. Accordingly, the term "spectrum" refers to frequencies (or wavelengths) not only in the visible range, but also frequencies (or wavelengths) in the infrared, ultraviolet, and other areas of the overall electromagnetic spectrum. Also, a given spectrum may have a relatively narrow bandwidth (essentially few frequency or wavelength components) or a relatively wide bandwidth (several frequency or wavelength components having various relative strengths). It should also be appreciated that a given spectrum may be the result of a mixing of two or more other spectrums (e.g., mixing radiation respectively emitted from multiple light sources).

For purposes of this disclosure, the term "color" is used interchangeably with the term "spectrum." However, the term "color" generally is used to refer primarily to a property of radiation that is perceivable by an observer (although this usage is not

intended to limit the scope of this term). Accordingly, the terms "different colors" implicitly refer to different spectrums having different wavelength components and/or bandwidths. It also should be appreciated that the term "color" may be used in connection with both white and non-white light.

The term "color temperature" generally is used herein in connection with white light, although this usage is not intended to limit the scope of this term. Color temperature essentially refers to a particular color content or shade (e.g., reddish, bluish) of white light. The color temperature of a given radiation sample conventionally is characterized according to the temperature in degrees Kelvin (K) of a black body radiator that radiates essentially the same spectrum as the radiation sample in question. The color temperature of white light generally falls within a range of from approximately 700 degrees K (generally considered the first visible to the human eye) to over 10,000 degrees K.

Lower color temperatures generally indicate white light having a more significant red component or a "warmer feel," while higher color temperatures generally indicate white light having a more significant blue component or a "cooler feel." By way of example, a wood burning fire has a color temperature of approximately 1,800 degrees K, a conventional incandescent bulb has a color temperature of approximately 2848 degrees K, early morning daylight has a color temperature of approximately 3,000 degrees K, and overcast midday skies have a color temperature of approximately 10,000 degrees K. A color image viewed under white light having a color temperature of approximately 3,000 degree K has a relatively reddish tone, whereas the same color image viewed under white light having a color temperature of approximately 10,000 degrees K has a relatively bluish tone.

Illuminators may be selected so as to produce a desired level of output, such as a desired total number of lumens of output, such as to make a lighting unit 102 consistent with or comparable to another lighting unit 102, which might be a semiconductor illuminator or might be another type of lighting unit, such as an incandescent,

fluorescent, halogen or other light source, such as if a designer or architect wishes to fit semiconductor-based lighting units 102 into installations that use such traditional units.

The number and type of semiconductor illuminators can be selected to produce the desired lumens of output, such as by selecting some number of one-watt, five-watt, power package or other LEDs. In embodiments two or three LEDs are chosen. In other embodiments any number of LEDs, such as six, nine, twenty, thirty, fifty, one hundred, three hundred or more LEDs can be chosen.

Referring to Fig. 4, a system 100 can include a secondary optical facility 400 to optically process the radiation generated by the light sources 300, such as to change one or both of a spatial distribution and a propagation direction of the generated radiation. In particular, one or more optical facilities may be configured to change a diffusion angle of the generated radiation. One or more optical facilities 400 may be particularly configured to variably change one or both of a spatial distribution and a propagation direction of the generated radiation (e.g., in response to some electrical and/or mechanical stimulus). An actuator 404, such as under control of a control facility 3500, can control an optical facility 400 to produce different optical effects.

Referring to Fig. 5, an optical facility 400 may be a diffuser 502. A diffuser may absorb and scatter light from a source 300, such as to produce a glowing effect in the diffuser. As seen in Fig. 5, diffusers 502 can take many different shapes, such as tubes, cylinders, spheres, pyramids, cubes, tiles, panels, screens, doughnut shapes, V-shapes, T-shapes, U-shapes, junctions, connectors, linear shapes, curves, circles, squares, rectangles, geometric solids, irregular shapes, shapes that resemble objects found in nature, and any other shape. Diffusers may be made of plastics, polymers, hydrocarbons, coated materials, glass materials, crystals, micro-lens arrays, fiber optics, or a wide range of other materials. Diffusers 502 can scatter light to provide more diffuse illumination of other objects, such as walls or alcoves. Diffusers 502 can also produce a glowing effect when viewed directly by a viewer. In embodiments, it may be desirable to deliver light evenly to the interior surface of a diffuser 502. For example, a reflector 600 may be

disposed under a diffuser 502 to reflect light to the interior surface of the diffuser 502 to provide even illumination.

Diffusing material can be a substantially light-transmissive material, such as a fluid, gel, polymer, gas, liquid, vapor, solid, crystal, fiber optic material, or other material. In embodiments the material may be a flexible material, so that the diffuser may be made flexible. The diffuser may be made of a flexible material or a rigid material, such as a plastic, rubber, a crystal, PVC, glass, a polymer, a metal, an alloy or other material.

Referring to Fig. 6, an optical facility 400 may include a reflector 600 for reflecting light from a light source 300. Embodiments include a parabolic reflector 612 for reflecting light from many angles onto an object, such as an object to be viewed in a machine vision system. Other reflectors 600 include mirrors, spinning mirrors 614, reflective lenses, and the like. In some cases, the optical facility 400 may operate under control of a processor 3600. Optical facilities 500 can also include lenses 402, including microlens arrays that can be disposed on a flexible material.

Other examples of optical facilities 400 include, but are not limited to, reflectors, lenses, reflective materials, refractive materials, translucent materials, filters, mirrors, spinning mirrors, dielectric mirrors, Bragg cells, MEMs, acousto-optic modulators, crystals, gratings and fiber optics. The optical facility 400 also may include a phosphorescent material, luminescent material, or other material capable of responding to or interacting with the generated radiation.

Variable optics can provide discrete or continuous adjustment of beam spread or angle or simply the profile of the light beam emitted from a fixture. Properties can include, but are not limited to, adjusting the profile for surfaces that vary in distance from the fixture, such as wall washing fixtures. In various embodiments, the variable nature of the optic can be manually adjusted, adjusted by motion control or automatically be controlled dynamically.

Referring to Fig. 7, actuation of variable optics can be through any kind of actuator, such as an electric motor, piezoelectric device, thermal actuator, motor, gyro, servo, lever, gear, gear system, screw drive, drive mechanism, flywheel, wheel, or one of many well-known techniques for motion control. Manual control can be through an adjustment mechanism that varies the relative geometry of lens, diffusion materials, reflecting surfaces or refracting elements. The adjustment mechanism may use a sliding element, a lever, screws, or other simple mechanical devices or combinations of simple mechanical devices. A manual adjustment or motion control adjustment may allow the flexing of optical surfaces to bend and shape the light passed through the system or reflected or refracted by the optical system.

Actuation can also be through an electromagnetic motor or one of many actuation materials and devices. Optical facilities 400 can also include other actuators, such as piezo-electric devices, MEMS devices, thermal actuators, processors, and many other forms of actuators.

A wide range of optical facilities 400 can be used to control light. Such devices as Bragg cells or holographic films can be used as optical facilities 400 to vary the output of a fixture. A Bragg cell or acoustic-optic modulator can provide for the movement of light with no other moving mechanisms. The combination of controlling the color (hue, saturation and value) as well as the form of the light beam brings a tremendous amount of operative control to a light source. The use of polarizing films can be used to reduce glare and allow the illumination and viewing of objects that present specular surfaces, which typically are difficult to view. Moving lenses and shaped non-imaging surfaces can provide optical paths to guide and shape light.

In other embodiments, fluid-filled surfaces 428 and shapes can be manipulated to provide an optical path. In combination with lighting units, such shapes can provide varying optical properties across the surface and volume of the fluid-filled material. The fluid-filled material can also provide a thermal dissipation mechanism for the light-

emitting elements. The fluid can be water, polymers, silicone or other transparent or translucent liquid or a gas of any type and mixture with desirable optical or thermal properties.

In other embodiments, gelled, filled shapes can be used in conjunction with light sources to evenly illuminate said shapes. Light propagation and diffusion is accomplished through the scattering of light through the shape.

In other embodiments, spinning mirror systems such as those used in laser optics for scanning (E.g. bar code scanners or 3D terrain scanners) can be used to direct and move a beam of light. That combined with the ability to rapidly turn on and off a lighting unit 102 can allow a beam of light to be spread across a larger area and change colors to 'draw' shapes of varying patterns. Other optical facilities 400 for deflecting and changing light patterns are known and described in the literature. They include methods for beam steering, such as mechanical mirrors, driven by stepper or galvanometer motors and more complex robotic mechanisms for producing sophisticated temporal effects or static control of both color (HS&V) and intensity. Optical facilities 400 also include acousto-optic modulators that use sound waves generated via piezoelectrics to control and steer a light beam. They also include digital mirror devices and digital light processors, such as available from Texas Instruments. They also include grating light valve technology (GLV), as well as inorganic digital light deflection. They also include dielectric mirrors, such as developed at Massachusetts Institute of Technology.

Control of form and texture of the light can include not only control of the shape of the beam but also control of the way in which the light is patterned across its beam. An example of a use of this technology may be in visual merchandising, where product 'spotlights' could be created while other media is playing in a coordinated manner. Voice-overs or music-overs or even video can be played during the point at which a product is highlighted during a presentation. Lights that move and 'dance' can be used in combination with A/V sources for visual merchandising purposes.

Optical facilities 400 can be light pipes, lenses, light guides and fibers and any other light transmitting materials.

In other embodiments, non-imaging optics are used as an optical facility. Non-imaging optics do not require traditional lenses. They use shaped surfaces to diffuse and direct light. A fundamental issue with fixtures using discrete light sources is mixing the light to reduce or eliminate color shadows and to produce uniform and homogenous light output. Part of the issue is the use of high efficiency surfaces that do not absorb light but bounce and reflect the light in a desired direction or manner. Optical facilities can be used to direct light to create optical forms of illumination from lighting units 102.

The actuator 404 can be any type of actuator for providing linear movement, such as an electromechanical element, a screw drive mechanism (such as used in computer printers), a screw drive, or other element for linear movement known to those of ordinary skill in the art.

In embodiments the optical facility is a fluid filled lens, which contains a compressible fluid, such as a gas or liquid. The actuator includes a valve for delivering fluid to the interior chamber of the lens.

In embodiments a digital mirror 408 serves as an optical facility 400. The digital mirror is optionally under control of a processor 3600, which governs the reflective properties of the digital mirror.

In embodiments a spinning mirror system 614 serves as an optical facility 400. As in other embodiments, the spinning mirror system is responsive to the control of a processor, which may be integrated with it or separate.

In embodiments a grating light valve (GLV) 418 serves as an optical facility 400. The grating light valve can receive light from a lighting unit under control of a processor.

GLV uses micro-electromechanical systems (MEMS) technology and optical physics to vary how light is reflected from each of multiple ribbon-like structures that represent a particular "image point" or pixel. The ribbons can move a tiny distance, such as between an initial state and a depressed state. When the ribbons move, they change the wavelength of reflected light. Grayscale tones can also be achieved by varying the speed at which given pixels are switched on and off. The resulting image can be projected in a wide variety of environments, such as a large arena with a bright light source or on a small device using low power light sources. In the GLV, picture elements (pixels) are formed on the surface of a silicon chip and become the source for projection.

In embodiments an acousto-optical modulator serves as an optical facility 400. Also known as a tunable filter and as a Bragg cell, the acousto-optical modulator consists of a crystal that is designed to receive acoustic waves generated, for example, by a transducer, such as a piezoelectric transducer. The acoustic standing waves produce index of refraction changes in the crystal, essentially due to a Doppler shift, so that the crystal serves as a tunable diffraction grating. Incident light, such as from a lighting unit 102, is reflected in the crystal by varying degrees, depending on the wavelength of the acoustic standing waves induced by the transducer. The transducer can be responsive to a processor, such as to convert a signal of any type into an acoustic signal that is sent through the crystal.

Referring again to Fig. 6, in embodiments the optical facility 400 is a reflector 612, such as a reflective dome for providing illumination from a wide variety of beam angles, rather than from one or a small number of beam angles. Providing many beam angles reduces harsh reflections and provides a smoother view of an object. A reflective surface is provided for reflecting light from a lighting unit 102 to the object. The reflective surface is substantially parabolic, so that light from the lighting unit 102 is reflected substantially to the object, regardless of the angle at which it hits the reflective surface from the lighting unit 102. The surface could be treated to a mirror surface, or to a matte Lambertian surface that reflects light substantially equally in all directions. As a result, the object is lit from many different angles, making it visible without harsh

reflections. The object may optionally be viewed by a camera, which may optionally be part of or in operative connection with a vision system. The camera may view the object through a space in the reflective surface, such as located along an axis of viewing from above the object. The object may rest on a platform, which may be a moving platform. The platform, light system 100, vision system and camera may each be under control of a processor, so that the viewing of the object and the illumination of the object may be coordinated, such as to view the object under different colors of illumination.

Referring to Fig. 7, optical facilities include a light pipe 420 that reflects light to produce a particular pattern of light at the output end. A different shape of light pipe produces a different pattern. In general, such secondary optics, whether imaging or non-imaging, and made of plastic, glass, mirrors or other materials, can be added to a lighting unit 102 to shape and form the light emission. Such an optical facility 400 can be used to spread, narrow, diffuse, diffract, refract or reflect the light in order that a different output property of the light is created. These can be fixed or variable. Examples can be light pipes, lenses, light guides and fibers and any other light transmitting materials, or a combination of any of these.

In embodiments the light pipe 420 serves as an optical facility, delivering light from one or more lighting systems 102 to an illuminated material. The lighting systems 100 are optionally controlled by a control facility 3500, which controls the lighting systems 102 to send light of selected colors, color temperatures, intensities and the like into the interior of the light pipe. In other embodiments a central controller is not required, such as in embodiments where the lighting systems 102 include their own processor. In embodiments one or more lighting systems 102 may be equipped with a communications facility, such as a data port, receiver, transmitter, or the like. Such lighting systems 102 may receive and transmit data, such as to and from other lighting systems 100. Thus, a chain of lighting systems 100 in a light pipe may transmit not only light, but also data along the pipe, including data that sends control signals for the lighting systems disposed in the pipe.

The optical facility may be a color mixing system 422 for mixing color from a lighting unit 102. The color mixing system may consist of two opposing truncated conical sections, which meet at a boundary. Light from a lighting unit 102 is delivered into the color mixing system and reflected from the interior surfaces of the two sections. The reflections mix the light and produce a mixed light from the distal end of the color mixing system. US Patent 2,686,866 to Williams, incorporated by reference herein, shows a color mixing lighting apparatus utilizing two inverted cones to reflect and mix the light from multiple sources. By combining a color mixing system such as this with color changes from the lighting unit 102, a user can produce a wide variety of lighting effects.

Other color mixing systems can work well in conjunction with color changing lighting systems 102. For example, US Patent 2, 673, 923 to Williams, also incorporated by reference herein, uses a series of lens plates for color mixing.

In embodiments an optical facility is depicted consisting of a plurality of cylindrical lens elements. These cylindrical elements diffract light from a lighting unit 102, producing a variety of patterns of different colors, based on the light from the lighting unit 102. The cylinders may be of a wide variety of sizes, ranging from microlens materials to conventional lenses.

In embodiments the optical facility 400 is a microlens array 424. The microlens array consists of a plurality of microscopic hexagonal lenses, aligned in a honeycomb configuration. Microlenses are optionally either refractive or diffractive, and can be as small as a few microns in diameter. Microlens arrays can be made using standard materials such as fused silica and silicon and newer materials such as Gallium Phosphide, making possible a very wide variety of lenses. Microlenses can be made on one side of a material or with lenses on both sides of a substrate aligned to within as little as one micron. Surface roughness values of 20 to 80 angstroms RMS are typical, and the addition of various coatings can produce optics with very high transmission rates. The

microlens array can refract or diffract light from a lighting unit 102 to produce a variety of effects.

In embodiments a microlens array optical facility 400 can consist of a plurality of substantially circular lens elements. The array can be constructed of conventional materials such as silica, with lens diameters on the range of a few microns. The array can operate on light from a lighting unit 102 to produce a variety of colors and optical effects.

In embodiments a microlens array is disposed in a flexible material, so that the optical facility 400 can be configured by bending and shaping the material that includes the array.

In embodiments a flexible microlens array is rolled to form a cylindrical shape for receiving light from a lighting unit 102. The configuration could be used, for example, as a light-transmissive lamp shade with a unique appearance.

In embodiments a system can be provided to roll a microlens array about an axis. A drive mechanism can roll or unroll the flexible array under control of a controller. The controller can also control a lighting unit 102, so that the array is disposed in front of the lighting unit 102 or rolled away from it, as selected by the user.

The terms "lighting unit," "luminaire" and "lighting fixture" are used herein to refer to an apparatus including one or more light sources 300. A given lighting unit 102 may have any one of a variety of mounting arrangements for the light source(s) in a variety of housings 800. Housings 800 may include enclosures, platforms, boards, mountings, and many other form factors, including forms designed for other purposes. Housings 800 may be made of any material, such as metals, alloys, plastics, polymers, and many others.

Referring to Fig. 8, housings 800 may include panels 804 that consist of a support platform on which light sources 300 are disposed in an array. Equipped with a diffuser 502, a panel 804 can form a light tile 802. The diffuser 502 for a light tile 802 can take many forms, as depicted in Fig. 8. The light tile 802 can be of any shape, such as square, rectangular, triangular, circular or irregular. The light tile 802 can be used on or as a part of a wall, door, window, ceiling, floor, or other architectural features, or as a work of art, or as a toy, novelty item, or item for entertainment, among other uses. Housings 800 may be configured as tiles or panels, such as for wall-hangings, walls, ceiling tiles, or floor tiles.

Referring to Fig. 9, housings 800 may include a housing for an architectural lighting fixture 810, such as a wall-washing fixture. Housings 800 may be square, rectangular 810, circular, cylindrical 812, or linear 814. A linear housing 814 may be equipped with a diffuser 502 to simulate a neon light of various shapes, or it may be provided without a diffuser, such as to light an alcove or similar location. A housing 800 may be provided with a watertight seal, to provide an underwater lighting system 818.

Housings 800 may be configured to resemble retrofit bulbs, fluorescent bulbs, incandescent bulbs, halogen lamps, high-intensity discharge lamps, or other kinds of bulbs and lamps. Housings 800 may be configured to resemble neon lights, such as for signs, logos, or decorative purposes. Housings 800 may be configured to highlight architectural features, such as lines of a building, room or architectural feature. Housings 800 may be configured for various industrial applications, such as medical lighting, surgical lighting, automotive lighting, under-car lighting, machine vision lighting, photographic lighting, lighting for building interiors or exteriors, lighting for transportation facilities, lighting for pools, spas, fountains and baths, and many other kinds of lighting.

Additionally, one or more lighting units similar to that described in connection with Fig. 2 may be implemented in a variety of products including, but not limited to, various forms of light modules or bulbs having various shapes and electrical/mechanical

coupling arrangements (including replacement or "retrofit" modules or bulbs adapted for use in conventional sockets or fixtures), as well as a variety of consumer and/or household products (e.g., night lights, toys, games or game components, entertainment components or systems, utensils, appliances, kitchen aids, cleaning products, etc.).

Lighting units 102 encompassed herein include lighting units 102 configured to resemble all conventional light bulb types, so that lighting units 102 can be conveniently retrofitted into fixtures, lamps and environments suitable for such environments. Such retrofitting lighting units 102 can be designed, as disclosed above and in the applications incorporated herein by reference, to use conventional sockets of all types, as well as conventional lighting switches, dimmers, and other controls suitable for turning on and off or otherwise controlling conventional light bulbs. Retrofit lighting units 102 encompassed herein include incandescent lamps, such as A15 Med, A19 Med, A21 Med, A21 3C Med, A23 Med, B10 Blunt Tip, B10 Crystal, B10 Candle, F15, GT, C7 Candle C7 DC Bay, C15, CA10, CA8, G16/1/2 Cand, G16-1/2 Med, G25 Med, G30 Med, G40 Med, S6 Cand, S6 DC Bay, S11 Cand, S11 DC Bay, S11 Inter, S11 Med, S14 Med, S19 Med, LINESTRA 2-base, T6 Cand, T7 Cand, T7 DC Bay, T7 Inter, T8 Cand, T8 DC Bay, T8 Inter, T10 Med, T6-1/2 Inter, T6-1/2 DC Bay, R16 Med, ER30 Med, ER40 Med, BR30 Med, BR40 Med, R14 Inter, R14 Med, K19, R20 Med, R30 Med, R40 Med, R40 Med Skrt, R40 Mog, R52 Mog, P25 Med, PS25 3C, PS25 Med, PS30 Med, PS35 Mog, PS52 Mog, PAR38 Med Skrt, PAR38 Med Sid Pr, PAR46 Scrw Trm, PAR46 Mog End Pr, PAR 46 Med Sid Pr, PAR56 Scrw Trm, PAR56 Mog End Pr, PAR 64 Scrw Trm, and PAR64 Ex Mog End Pr. Also, retrofit lighting units 102 include conventional tungsten/halogen lamps, such as BT4, T3, T4 BI-PIN, T4 G9, MR16, MR11, PAR14, PAR16, PAR16 GU10, PAR20, PAR30, PAR30LN, PAR36, PAR38 Medium Skt., PAR38 Medium Side Prong, AR70, AR111, PAR56 Mog End Pr, PAR64 Mog End Pr, T4 DC Bayonet, T3, T4 Mini Can, T3, T4 RSC Double End, T10, and MB19. Lighting units 102 can also include retrofit lamps configured to resemble high intensity discharge lamps, such as E17, ET18, ET23.5, E25, BT37, BT56, PAR20, PAR30, PAR38, R40, T RSC base, T Fc2 base, T G12 base, T G8.5 base, T Mogul base, and TBY22d base lamps. Lighting units 102 can also be configured to resemble fluorescent lamps, such

as T2 Axial Base, T5 Miniature Bipin, T8 Medium Bipin, T8 Medium Bipin, T12 Medium Bipin, U-shaped t-12, OCTRON T-8 U-shaped, OCTRON T8 Recessed Double Contact, T12 Recessed Double Contact, T14-1/2 Recessed Double Contact, T6 Single Pin, T8 Single Pin, T12 Single Pin, ICETRON, Circline 4-Pin T-19, PENTRON CIRCLINE 4-pin T5, DULUX S, DULUX S/E, DULUX D, DULUX D/E, DULUX T, DULUX T/E, DULUX T/E/IN, DULUX L, DULUX F, DULUX EL Triple, DULUX EL TWIST DULUX EL CLASSIC, DULUX EL BULLET, DULUX EL Low Profile GLOBE, DULUX EL GLOBE, DULUE EL REFLECTOR, and DULUX EL Circline. Lighting units 102 can also include specialty lamps, such as for medical, machine vision, or other industrial or commercial applications, such as airfield/aircraft lamps, audio visual maps, special purpose heat lamps, studio, theatre, TV and video lamps, projector lamps, discharge lamps, marine lamps, aquatic lamps, and photo-optic discharge lamps, such as HBO, HMD, HMI, HMP, HSD, HSR, HTI, LINEX, PLANON, VIP, XBO and XERADEX lamps. Other lamps types can be found in product catalog for lighting manufacturers, such as the Sylvania Lamp and Ballast Product Catalog 2002, from Sylvania Corporation or similar catalogs offered by General Electric and Philips Corporation.

In embodiments the lighting system may have a housing configured to resemble a fluorescent or neon light. The housing may be linear, curved, bent, branched, or in a "T" or "V" shape, among other shapes.

Housings 800 can take various shapes, such as one that resembles a point source, such as a circle or oval. Such a point source can be located in a conventional lighting fixture, such as lamp or a cylindrical fixture. Lighting units 102 can be configured in substantially linear arrangements, either by positioning point sources in a line, or by disposing light sources substantially in a line on a board located in a substantially linear housing, such as a cylindrical housing. A linear lighting unit can be placed end-to-end with other linear elements or elements of other shapes to produce longer linear lighting systems comprised of multiple lighting units 102 in various shapes. A housing can be curved to form a curvilinear lighting unit. Similarly, junctions can be created with

branches, “Ts,” or “Ys” to create a branched lighting unit. A bent lighting unit can include one or more “V” elements. Combinations of various configurations of point source, linear, curvilinear, branched and bent lighting units 102 can be used to create any shape of lighting system, such as one shaped to resemble a letter, number, symbol, logo, object, structure, or the like.

Housings 800 can include or be combined to produce three-dimensional configurations, such as made from a plurality of lighting units 102. Linear lighting units 102 can be used to create three-dimensional structures and objects, or to outline existing structures and objects when disposed along the lines of such structures and objects. Many different displays, objects, structures, and works of art can be created using linear lighting units as a medium. Examples include pyramid configurations, building outlines and two-dimensional arrays. Linear units in two-dimensional arrays can be controlled to act as pixels in a lighting show.

In embodiments the housing 800 may be a housing for an architectural, theatrical, or entertainment lighting fixture, luminaire, lamp, system or other product. The housing 800 may be made of a metal, a plastic, a polymer, a ceramic material, glass, an alloy or another suitable material. The housing 800 may be cylindrical, hemispherical, rectangular, square, or another suitable shape. The size of the housing may range from very small to large diameters, depending on the nature of the lighting application. The housing 800 may be configured to resemble a conventional architectural lighting fixture, such as to facilitate installation in proximity to other fixtures, including those that use traditional lighting technologies such as incandescent, fluorescent, halogen, or the like. The housing 800 may be configured to resemble a lamp. The housing 800 may be configured as a spot light, a down light, an up light, a cove light, an alcove light, a sconce, a border light, a wall-washing fixture, an alcove light, an area light, a desk lamp, a chandelier, a ceiling fan light, a marker light, a theatrical light, a moving-head light, a pathway light, a cove light, a recessed light, a track light, a wall fixture, a ceiling fixture, a floor fixture, a circular fixture, a spherical fixture, a square fixture, a rectangular fixture, an accent light, a pendant, a parabolic fixture, a strip light, a soffit light, a

valence light, a floodlight, an indirect lighting fixture, a direct lighting fixture, a flood light, a cable light, a swag light, a picture light, a portable luminaire, an island light, a torchiere, a boundary light, a flushor any other kind architectural or theatrical lighting fixture or luminaire.

Housings may also take appropriate shapes for various specialized, industrial, commercial or high performance lighting applications. For example, in an embodiment a miniature system, such as might be suitable for medical or surgical applications or other applications demanding very small light systems 100, can include a substantially flat light shape, such as round, square, triangular or rectangular shapes, as well as non-symmetric shapes such as tapered shapes. In many such embodiments, housing 800 could be generally described as a planar shape with some small amount of depth for components. The housing 800 can be small and round, such as about ten millimeters in diameter (and can be designed with the same or similar configuration at many different scales). The housing 800 may include a power facility, a mounting facility and an optical facility. The housing 800 and optical facility can be made of metals or plastic materials suitable for medical use.

Referring to Fig. 10, a housing 800 for a lighting unit 100 may serve as a housing for another object as well, such as a compact 1002, a flashlight 1004, a ball 1008, a mirror 1012, an overhead light 1014, a wand 1010, a traffic light 1020, a mirror 1018, a sign 1022, a toothbrush 1024, a cube 1028 (such as a Lucite cube), a display 1030, a handheld computer 1032, a phone 1034, or a block 1038. Almost any object can be integrated with a lighting unit 102 to provide a controlled lighting feature.

Fig. 11 shows additional housings 800 for lighting units 102, such as blocks 1104, balls 1108, pucks 1110, spheres 1112, and lamps 1114.

Referring to Fig. 11, housings 800 may also take the form of a flexible band 1102, tape or ribbon to allow the user to conform the housing to particular shapes or cavities. Similarly, housings 800 can take the form of a flexible string 1104. Such a

band 1102 or string 1104 can be made in various lengths, widths and thicknesses to suit specific demands of applications that benefit from flexible housings 800, such as for shaping to fit body parts or cavities for surgical lighting applications, shaping to fit objects, shaping to fit unusual spaces, or the like. In flexible embodiments it may be advantageous to use thin-form batteries, such as polymer or "paper" batteries for small bands 1102 or strings 1104.

Referring to Fig. 12, lighting units 102 can be disposed in a sign 1204, such as to provide lighting. Combined with diffusers 502, the lighting units 102 can produce an effect similar to neon lights. Signs 1204 can take many different forms, with lighting units 102, housings 800 and diffusers 502 shaped to resemble logos, characters, numbers, symbols, and other signage elements. In embodiments the sign 1204 can be made of light-transmissive materials. Thus, a sign 1204 can glow with light from the lighting units 102, similar to the way a neon light glows. The sign 1204 can be configured in letters, symbols, numbers, or other configurations, either by constructing it that way, or by providing sub-elements that are fit together to form the desired configuration. The light from the lighting units 102 can be white light, other colors of light, or light of varying color temperatures. In an embodiment the sign 1204 can be made from a kit that includes various sub-elements, such as curved elements, straight elements, "T" junctions, "V-" and "U-" shaped elements, and the like.

In embodiments a housing 800 may be configured as a sphere or ball, so as to produce light in substantially all directions. The ball housing 800 can be made of plastic or glass material that could be transparent for maximum light projection or diffuse to provide softer light output that is less subject to reflections. The ball housing 800 could be very small, such as the size of a marble or a golf ball, so that it is easily managed in environments that require miniature light systems 100, or it could be very large, such as in art, architectural, and entertainment applications. Multiple balls can be used simultaneously to provide additional light. If it is desired to have directional light from a ball lighting system 100, then part of the ball can be made dark.

Housings 800 can incorporate lighting units 102 into conventional objects, such as tools, utensils, or other objects. For example, a housing 800 may be shaped into a surgical tool, such as tweezers, forceps, retractors, knives, scalpels, suction tubes, clamps or the like. A lighting unit 102 can be collocated at the end of a tool and provide illumination to the working area of the tool. One of many advantages of this type of tool is the ability to directly illuminate the working area, avoiding the tendency of tools or the hands that use them to obscure the working area. Tools can have onboard batteries or include other power facilities as described herein.

Housings 800 can also be configured as conventional tools with integrated lighting units 102, such as hammers, screw drivers, wrenches (monkey wrenches, socket wrenches and the like), pliers, vise-grips, awls, knives, forks, spoons, wedges, drills, drill bits, saws (circular saws, jigsaws, mitre saws and the like), sledge hammers, shovels, digging tools, plumbing tools, trowels, rakes, axes, hatchets and other tools. As with surgical tools, including the lighting unit 102 as part of the tool itself allows lighting a work area or work piece without the light being obscured by the tool or the user.

Referring to Fig. 13, a housing may be configured to resemble a conventional MR-type halogen fixture 1300. A rectangular opening 1302 in the housing 800 allows the positioning of a connector that serves as an interface 4904 between a socket into which the housing 800 is positioned and a board 204 that bears the light sources 300, which include a plurality of LEDs. The interface 4904 provides a mechanical, electrical and data connection between the board 204 and the socket into which the housing 800 is placed.

Referring to Figs. 14a and 14b, a housing 800 may be a linear housing 1402. Referring to Fig. 14a, the housing may include connectors 1404 located at the ends of the linear housing 1402, so that separate modular units of the housing 1402 can be connected end-to-end at a junction 1412 with little spacing in between. The connectors 1404 of Fig. 14b extend from the housing 800. The connectors 1404 can be designed to transmit power and data from one lighting unit 102 to another lighting unit 102 having a similar

linear housing 1402. The top of the housing can include a slot 1408 into which light sources 300 are disposed. The housing 800 can be fit with a lens 1412 for protecting the light sources 300 or shaping light coming from the light sources 300. The lens 1412 can be provided with a very tight seal, such as to prevent a user from touching the light sources 300 or any of the drive circuitry. In embodiments the housing 1402 may house drive circuitry for a high-voltage embodiment, as described in more detail below and in applications incorporated herein by reference. In embodiments the housing 1402 may include a cover 1414 for covering the connector 1404 if the connector is not in use. The linear housing 1402 can be deployed to produce many different effects in many different environments, as described in connection with other linear embodiments described herein. In one preferred embodiment, lighting units 102 with linear housings 1402 are strung end-to-end in an alcove to light the alcove. In another preferred embodiments, such lighting units 102 with linear housings 1402 are connected end-to-end across the base of a wall or other architectural feature to wash the wall or other feature with light of varying colors.

In embodiments a light source 300 may be equipped with a primary optical facility 1700, such as a lens, diode package, or phosphor for shaping, spreading or otherwise optically operating on photons that exit the semiconductor in an LED. For example, a phosphor may be used to convert UV or blue radiation coming out of a light source 300 into broader band illumination, such as white illumination. Primary optical facilities may include packages such as those used for one-watt, three-watt, five-watt and power packages offered by manufacturers such as LumiLeds, Nichia, Cree and Osram-Opto.

In one embodiment, the lighting unit 102 or a light source 300 of Figs. 1 and 2 may include and/or be coupled to a power facility 1800. In various aspects, examples of power facilities 1800 include, but are not limited to, AC power sources, DC power sources, batteries, solar-based power sources, thermoelectric or mechanical-based power sources and the like. Additionally, in one aspect, the power facility 1800 may include or

be associated with one or more power conversion devices that convert power received by an external power source to a form suitable for operation of the lighting unit 102.

Light sources 300 have varying power requirements. Accordingly, lighting units 102 may be provided with dedicated power supplies that take power from power lines and convert it to power suitable for running a lighting unit 102. Power supplies may be separate from lighting units 102 or may be incorporated on-board the lighting units 102 in power-on-board configurations. Power supplies may power multiple lighting units 102 or a single lighting unit 102. In embodiments power supplies may provide low-voltage output or high-voltage output. Power supplies may take line voltage or may take power input that is interrupted or modified by other devices, such as user interfaces 4908, such as switches, dials, sliders, dimmers, and the like.

In embodiments a line voltage power supply is integrated into a lighting system 100 and a power line carrier (PLC) serves as a power facility 1800 and as a control facility 3500 for delivering data to the lighting units 102 in the lighting system 100 over the power line. In other cases a lighting system 100 ties into existing power systems (120 or 220VAC), and the data is separately wired or provided through wireless.

A power facility 1800 may include a battery, such as a watch-style battery, such as Lithium, Alkaline, Silver-Zinc, Nickel-Cadmium, Nickel metal hydride, Lithium ion and others. The power facility 1800 may include a thin-form polymer battery that has the advantage of being very low profile and flexible, which can be useful for lighting unit configurations in flexible forms such as ribbons and tape. A power facility 1800 may also comprise a fuel cell, photovoltaic cell, solar cell or similar energy-producing facility. A power facility 1800 may be a supercapacitor, a large-value capacitor that can store much more energy than a conventional capacitor. Charging can be accomplished externally through electrical contacts and the lighting device can be reused. A power facility 1800 can include an inductive charging facility. An inductive charging surface can be brought in proximity to a lighting unit 102 to charge an onboard power source,

allowing, for example, a housing 800 to be sealed to keep out moisture and contaminants.

Battery technologies typically generate power at specific voltage levels such as 1.2 or 1.5V DC. LED light sources 300, however, typically require forward voltages ranging from around 2VDC to 3.2VDC. As a result batteries may be put in series to achieve the required voltage, or a boost converter may be used to raise the voltage.

It is also possible to use natural energy sources as a power facility 1800, such as solar power, the body's own heat, mechanical power generation, the body's electrical field, wind power, water power, or the like.

Referring to Fig. 15, in embodiments it is desirable to supply power factor correction (PFC) to power for a lighting unit 102. In a power-factor-corrected lighting system 102, a line interference filter and rectifier 1802 may be used to remove interference from the incoming line power and to rectify the power. The rectified power can be delivered to a power factor corrector 1804 that operates under control of a control circuit 1810 to provide power factor correction, which is in turn used to provide a high voltage direct current output 1808 to the lighting unit 102. Many embodiments of power factor correction systems can be used as alternatives to the embodiment of Fig. 15.

Fig. 16a shows an embodiment of a lighting system 100 with a power factor correction facility 1804. The line filter and rectifier 1802 takes power from the line, filters and rectifies the power, and supplies it to the power factor correction facility 1804. The embodiment of Fig. 16a includes a DC to DC converter 1812 that converts the output of the power factor correction facility 1804 to, for example, twenty-four volt power for delivery via a bus. The bus also carries data from a data converter 1904, which carries a control signal for the lighting units 102 that are attached to the bus that carries both the power and the data. In the embodiment of Fig. 16b, the DC to DC converter 1812 is disposed locally at each lighting unit 102, rather than in a central power supply as in Fig. 16a.

Fig. 17 shows an embodiment where the power factor correction facility 1804 and DC to DC converter 1812 are integrated into a single stage power factor correction/DC to DC converter facility 1908 that is integrated with the lighting unit 102, rather than being contained in a separate power supply. The alternating current line power is delivered to a high-voltage three wire power/data bus 1910 that also carries input from a data converter 1904 that carries control signals for the lighting unit 102. Power factor correction and conversion to DC output voltages suitable for light sources 300 such as LEDs occurs at the lighting units 102. Unlike conventional power supplies where power factor correction is absent or present only in a separate power supply, the local power factor correction/DC to DC converter 1908 can take line voltage and correct it to an appropriate input for a LED light source 300 even if the line voltage has degraded substantially after a long run of wire. The configuration of Fig. 17 and other alternative embodiments that supply power factor correction and voltage conversion on board allow lighting units 102 to be configured in long strings over very large geometries, without the need to install separate power supplies for each lighting unit 102. Accordingly, it is one preferred embodiment of a power supply for disposing lighting units 102 on building exteriors and other large environments where it is inconvenient to install or maintain many separate power supplies.

In embodiments it is desirable to provide power and data over the same line. Referring to Fig. 18, a multiplexer 1850 takes a data input and a direct current power input and combines them to provide a combined power and data signal. 1852.

Semiconductor devices like LED light sources 300 can be damaged by heat; accordingly, a system 100 may include a thermal facility 2500 for removing heat from a lighting unit 102. Referring to Fig. 19, the thermal facility 2500 may be any facility for managing the flow of heat, such as a convection facility 2700, such as a fan 2702 or similar mechanism for providing air flow to the lighting unit 102, a pump or similar facility for providing flow of a heat-conducting fluid, a vent 2704 for allowing flow of air, or any other kind of convection facility 2700. A fan 2702 or other convection

facility 2700 can be under control of a processor 3600 and a temperature sensor such as a thermostat to provide cooling when necessary and to remain off when not necessary.

The thermal facility 2500 can also be a conduction facility 2600, such as a conducting plate or pad of metal, alloy, or other heat-conducting material, a gap pad 2602 between a board 204 bearing light sources 300 and another facility, a thermal conduction path between heat-producing elements such as light sources 300 and circuit elements, or a thermal potting facility, such as a polymer for coating heat-producing elements to receive and trap heat away from the light sources 300. The thermal facility 2500 may be a radiation facility 2800 for allowing heat to radiate away from a lighting unit 102. A fluid thermal facility 2900 can permit flow of a liquid or gas to carry heat away from a lighting unit 102. The fluid may be water, a chlorofluorocarbon, a coolant, or the like. In a preferred embodiment a conductive plate is aluminum or copper. In embodiments a thermal conduction path 2720 conducts heat from a circuit board 204 bearing light sources 300 to a housing 800, so that the housing 800 radiates heat away from the lighting unit 102.

Referring to Fig. 20, a mechanical interface 3200 may be provided for connecting a lighting unit 102 or light source 300 mechanically to a platform, housing 800, mounting, board, other lighting unit 102, or other product or system. In embodiments the mechanical interface 3200 may be a modular interface for removably and replaceably connecting a lighting unit 102 to another lighting unit 102 or to a board 204. A board 204 may include a lighting unit 102, or it may include a power facility for a lighting unit 102.

In embodiments the modular interface 3202 comprises a board 204 with a light source 300 on one side and drive circuit elements on the other side, or two boards 204 with the respective elements on opposite sides and the boards 204 coupled together. The modular interface 3202 may be designed to allow removal or replacement of a lighting unit 102, either in the user environment of the lighting unit 102 or at the factory. In embodiments a lighting unit 102 has a mechanical retrofit interface 3300 for allowing it

to fit the housing of a traditional lighting source, such as a halogen bulb 3302. In embodiments the modular interface 3200 is designed to allow multiple lighting units 102 to fit together, such as a modular block 3204 with teeth, slots, and other connectors that allow lighting units 102 to serve as building blocks for larger systems of lighting units 102.

In embodiments the retrofit interface 3300 allows the lighting unit 102 to retrofit into the mechanical structure of a traditional lighting source, such as screw for an Edison-mount socket, pins for a Halogen socket, ballasts for a fluorescent fixture, or the like.

In embodiments the mechanical interface is a socket interface 3400, such as to allow the lighting unit 102 to fit into any conventional type of socket, which in embodiments may be a socket equipped with a control facility 3500, i.e., a smart socket.

In embodiments the mechanical interface 3200 is a circuit board 204 on which a plurality of light sources 300 are disposed. The board 204 can be configured to fit into a particular type of housing 800, such as any of the housings 800 described above. In embodiments the board 204 may be moveably positioned relative to the position of the housing 800. A control facility may adjust the position of the board 204.

A kit may be provided for producing an illumination system, which may include light sources 300, components for a control facility 3500, and instructions for using the control facility components to control the light sources 300 to produce an illumination effect.

In embodiments a control facility 3500 for a light source 300 may be disposed on a second board 204, so that the control facility 3500 can be moveably positioned relative to the board 204 on which the light sources 300 are disposed. In embodiments the board for the control facility 3500 and the board 204 for the light sources 300 are configured to

mechanically connect in a modular way, permitting removal and replacement of one board 204 relative to the other, whether during manufacturing or in the field.

A developer's kit may be provided including light sources 300, a circuit board 204 and instructions for integrating the board 204 into a housing 800. A board 204 with light sources 300 may be provided as a component for a manufacturer of a lighting system 100. The component may further include a chip, firmware, and instructions or specifications for configuring the system into a lighting system 100.

In embodiments a board 204 carrying LEDs may be configured to fit into an architectural lighting fixture housing 800 or other housing 800 as described above.

In embodiments, a light source 300 can be configured with an off-axis mounting facility or a light shade that selectively allows light to shine through in certain areas and not in others. These techniques can be used to reduce glare and light shining directly into the eyes of a user of the lighting unit 102. Snap-on lenses can be used atop the light-emitting portion to allow for a much wider selection of light patterns and optical needs. In embodiments a disk-shaped light source 300 emits light in one off-axis direction. The light can then be rotated about the center axis to direct the light in a desired direction. The device may be simply picked up, rotated, and placed back down using the fastening means such as magnetic or clamp (see below for more fastening options) or may simply incorporate a rotational mechanism.

Referring to Fig. 21, in embodiments the mechanical interface 3200 may connect light sources 300 to fiber bundles 2102 to create flexible lighting units 102. A lighting unit 102 can be configured to be incorporated directly in a tool 2104, so that the fiber transports the light to another part of the tool 2104. This would allow the light source 300 to be separated from the 'working' end of the tool 2104 but still provide the lighting unit 102 without external cabling and with only a short efficient length of fiber. An electro-luminescent panel can be used wherein the power is supplied via onboard power in the form of a battery or a cable or wire to an off board source.

A mechanical interface 3200 may include facilities for fastening lighting units 102 or light sources 300, such as to platforms, tools, housing or the like. Embodiments include a magnetic fastening facility. In embodiments a lighting unit 102 is clamped or screwed into a tool or instrument. For example, a screw-type clamp 2108 can be used to attach a lighting unit 102 to another surface. A toggle-type clamp can be used, such as De-Sta-Co style clamps as used in the surgical field. A clip or snap-on facility can be used to attach a lighting unit 102 and allow flexing elements. A flexible clip 2110 can be added to the back of a lighting device 102 to make it easy to attach to another surface. A spring-clip, similar to a binder clip, can be attached to the back of a lighting unit 102. A flexing element can provide friction when placed on another surface. Fasteners can include a spring-hinge mechanism, string, wire, Ty-wraps, hook and loop fastener 2114, adhesives or the like. Fastening materials include bone wax 2112; a beeswax compound (sometimes mixed with Vaseline), which can be hand, molded, and can also be used for holding the lighting device 102. The exterior of the lighting device 102 can be textured to provide grip and holding power to facilitate the fastening. Tapes, such as surgical DuoPlas tape from Sterion, are another example of materials that can be used to fasten the light to tools, instruments, and drapes or directly to the patient.

Mechanical interfaces 3200 configured as boards 204 on which light sources 300 are disposed can take many shapes, including shapes that allow the boards 204 to be used as elements, such as tiles, to make up larger structures. Thus, a board 204 can be a triangle 2118, square 2120, hexagon, or other element that can serve as a subunit of a larger pattern, such as a two-dimensional planar pattern or a three-dimensional object, such as a regular polyhedron or irregular object.

Referring to Fig. 22, boards 204 can provide a mechanical and electrical connection 2202, such as with matching tabs and spaces that fit into each other to hold the boards 204 together. Such boards can build large structures. For example, a large number of triangular boards 2118 can be arranged together to form a substantially spherical configuration 2204 that resembles a large ball, with individual lighting units

102 distributed about the entire perimeter to shine light in substantially all directions from the ball sphere 2204.

Fig. 14 showed a mechanical interface 3200 for connecting two linear lighting units 102 end-to-end. Another mechanical interface 3200 is seen in Fig. 23, where cables 2322 exit a portal 2324 in the housing 800 and enter a similar portal 2324 in the housing 800 of the next linear unit 102, so that the two units 102 can be placed end-to-end. A protective cover 2320 can cover the cables 2322 between the units 102. The cables 2322 can carry power and data between the units 102.

In embodiments, mechanical interfaces 3200 can include thermal facilities 2500 such as those described above as well as facilities for delivering power and data.

A control facility 3500 may produce a signal for instructing a light system 100 lighting unit 102 to produce a desired light output, such as a mixture of light from different light sources 300. Control facilities can be local to a lighting unit 102 or remote from the lighting unit 102. Multiple lighting units 102 can be linked to central control facilities 3500 or can have local control facilities 3500. Control facilities can use a wide range of data protocols, ranging from simple switches for "on" and "off" capabilities to complex data protocols such as Ethernet and DMX.

Referring to Fig. 24a, a control facility 3500 may include drive hardware 3800 for delivering controlled current to one or more light sources 300. Referring to Figs. 24a and 24b, control signals from a control facility 3500, such as a central data source, are used by a processor 3600 that controls the drive hardware 3800, causing current to be delivered to the light sources 300 in the desired intensities and durations, often in very rapid pulses of current, such as in pulse width modulation or pulse amplitude modulation, or combinations of them, as described below. Two examples of drive hardware 3800 circuits are shown in Fig. 24, but many alternative embodiments are possible, including those described in the patent incorporated by reference herein. Referring to Fig. 24c in embodiments power from a power facility 1800 and data from a

control facility 3500 are delivered together as an input 2402. A dipswitch 2408 can be used to provide a processor 3600 with a unique address, so that the lighting unit 102 responds to control signals intended for that particular lighting unit 102. The processor 3600 reads the power/data input and drives the drive hardware 3800 to provide current to the light sources 300.

In embodiments the control facility 3500 includes the processor 3600. "Processor" or "controller" describes various apparatus relating to the operation of one or more light sources. A processor or controller can be implemented in numerous ways, such as with dedicated hardware, using one or more microprocessors that are programmed using software (e.g., microcode or firmware) to perform the various functions discussed herein, or as a combination of dedicated hardware to perform some functions and programmed microprocessors and associated circuitry to perform other functions. The terms "program" or "computer program" are used herein in a generic sense to refer to any type of computer code (e.g., software or microcode) that can be employed to program one or more processors or controllers, including by retrieval of stored sequences of instructions.

In particular, in a networked lighting system environment, as discussed in greater detail further below (e.g., in connection with Fig. 2), as data is communicated via the network, the processor 3600 of each lighting unit coupled to the network may be configured to be responsive to particular data (e.g., lighting control commands) that pertain to it (e.g., in some cases, as dictated by the respective identifiers of the networked lighting units). Once a given processor identifies particular data intended for it, it may read the data and, for example, change the lighting conditions produced by its light sources according to the received data (e.g., by generating appropriate control signals to the light sources). In one aspect, a data facility 3700 of each lighting unit 102 coupled to the network may be loaded, for example, with a table of lighting control signals that correspond with data the processor 3600 receives. Once the processor 3600 receives data from the network, the processor may consult the table to select the control signals that

correspond to the received data, and control the light sources of the lighting unit accordingly.

In one aspect of this embodiment, the processor 3600 of a given lighting unit, whether or not coupled to a network, may be configured to interpret lighting instructions/data that are received in a DMX protocol (as discussed, for example, in U.S. Patents 6,016,038 and 6,211,626), which is a lighting command protocol conventionally employed in the lighting industry for some programmable lighting applications. However, it should be appreciated that lighting units suitable for purposes of the present invention are not limited in this respect, as lighting units according to various embodiments may be configured to be responsive to other types of communication protocols so as to control their respective light sources.

In other embodiments the processor 3600 may be an application specific integrated circuit, such as one configured to respond to instructions according to a protocol, such as the DMX protocol, Ethernet protocols, or serial addressing protocols where each ASIC responds to control instructions directed to it, based on the position of the ASIC in a string of similar ASICs.

In various implementations, a processor or controller may be associated with a data facility 3700, which can comprise one or more storage media (generically referred to herein as "memory," e.g., volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM, floppy disks, compact disks, optical disks, magnetic tape, etc.). In some implementations, the storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform at least some of the functions discussed herein. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller so as to implement various aspects of the present invention discussed herein.

In embodiments the data storage facility 3700 stores information relating to control of a lighting unit 102. For example, the data storage facility may be memory employed to store one or more lighting programs for execution by the processor 3600 (e.g., to generate one or more control signals for the light sources), as well as various types of data useful for generating variable color radiation (e.g., calibration information, information relating to techniques for driving light sources 300, information relating to addresses for lighting units 102, information relating to effects run on lighting units 102, and may other purposes as discussed further herein). The memory also may store one or more particular identifiers (e.g., a serial number, an address, etc.) that may be used either locally or on a system level to identify the lighting unit 102. In various embodiments, such identifiers may be pre-programmed by a manufacturer or alterable by the manufacturer, for example, and may be either alterable or non-alterable thereafter (e.g., via some type of user interface located on the lighting unit, via one or more data or control signals received by the lighting unit, etc.). Alternatively, such identifiers may be determined at the time of initial use of the lighting unit in the field, and again may be alterable or non-alterable thereafter. The data storage facility 3700 may also be a disk, diskette, compact disk, random access memory, read only memory, SRAM, DRAM, database, data mart, data repository, cache, queue, or other facility for storing data, such as control instructions for a control facility 3500 for a lighting unit 102. Data storage may occur locally with the lighting unit, in a socket or housing 800, or remotely, such as on a server or in a remote database. In embodiments the data storage facility 3700 comprises a player that stores shows that can be triggered through a simple interface.

The drive facility 3800 may include drive hardware 3802 for driving one or more light sources 300. In embodiments the drive hardware 3802 comprises a current sink, such as a switch 3900, such as for turning on the current to a light source 300. In embodiments the switch 3900 is under control of the processor 3600, so that the switch 3900 can turn on or off in response to control signals. In embodiments the switch turns on and off in rapid pulses, such as in pulse width modulation of the current to the LEDs, which results in changes in the apparent intensity of the LED, based on the percentage of

the duty cycle of the pulse width modulation technique during which the switch is turned on.

The drive hardware 3802 may include a voltage regulator 4000 for controlling voltage to a light source, such as to vary the intensity of the light coming from the light source 300.

The drive hardware 3802 may include a feed-forward drive circuit 4100 such as described in the patent applications incorporated herein by reference.

The drive hardware 3802 may include an inductive loop drive circuit 4200 such as in the patent applications incorporated herein by reference.

Various embodiments of the present invention are directed generally to methods and apparatus for providing and controlling power to at least some types of loads, wherein overall power efficiency typically is improved and functional redundancy of components is significantly reduced as compared to conventional arrangements. In different aspects, implementations of methods and apparatus according to various embodiments of the invention generally involve significantly streamlined circuits having fewer components, higher overall power efficiencies, and smaller space requirements.

In some embodiments, a controlled predetermined power is provided to a load without requiring any feedback information from the load (i.e., without monitoring load voltage and/or current). Furthermore, in one aspect of these embodiments, no regulation of load voltage and/or load current is required. In another aspect of such embodiments in which feedback is not required, isolation components typically employed between a DC output voltage of a DC-DC converter (e.g., the load supply voltage) and a source of power derived from an AC line voltage (e.g., a high DC voltage input to the DC-DC converter) in some cases may be eliminated, thereby reducing the number of required circuit components. In yet another aspect, eliminating the need for a feedback loop

generally increases circuit speed and avoids potentially challenging issues relating to feedback circuit stability.

Based on the foregoing concepts, one embodiment of the present invention is directed to a "feed-forward" driver for an LED-based light source. Such a feed-forward driver combines the functionality of a DC-DC converter and a light source controller, and is configured to control the intensity of light generated by the light source based on modulating the average power delivered to the light source in a given time period, without monitoring or regulating the voltage or current provided to the light source. In one aspect of this embodiment, the feed-forward driver is configured to store energy to and release energy from an energy transfer device using a "discontinuous mode" switching operation. This type of switching operation facilitates the transfer of a predictable quantum of energy per switching cycle, and hence a predictable controlled power delivery to the light source.

In embodiments the drive hardware 3802 includes at least one energy transfer element to store input energy based on an applied input voltage and to provide output energy to a load at an output voltage. The drive hardware 3802 may include at least one switch coupled to the at least one energy transfer element to control at least the input energy stored to the at least one energy transfer element and at least one switch controller configured to control the at least one switch, wherein the at least one switch controller does not receive any feedback information relating to the load to control the at least one switch.

As shown in Fig. 1, the lighting unit 102 also may include the processor 3600 that is configured to output one or more control signals to drive the light sources 300 so as to generate various apparent intensities of light from the light sources. For example, in one implementation, the processor 3600 may be configured to output at least one control signal for each light source so as to independently control the intensity of light generated by each light source. Some examples of control signals that may be generated by the processor to control the light sources include, but are not limited to, pulse modulated

signals, pulse width modulated signals (PWM), pulse amplitude modulated signals (PAM), pulse displacement modulated signals, analog control signals (e.g., current control signals, voltage control signals), combinations and/or modulations of the foregoing signals, or other control signals. In one aspect, the processor 3600 may control other dedicated circuitry that in turn controls the light sources so as to vary their respective intensities.

Lighting systems in accordance with this specification can operate light sources 300 such as LEDs in an efficient manner. Typical LED performance characteristics depend on the amount of current drawn by the LED. The optimal efficacy may be obtained at a lower current than the level where maximum brightness occurs. LEDs are typically driven well above their most efficient operating current to increase the brightness delivered by the LED while maintaining a reasonable life expectancy. As a result, increased efficacy can be provided when the maximum current value of the PWM signal may be variable. For example, if the desired light output is less than the maximum required output the current maximum and/or the PWM signal width may be reduced. This may result in pulse amplitude modulation (PAM), for example; however, the width and amplitude of the current used to drive the LED may be varied to optimize the LED performance. In an embodiment, a lighting system may also be adapted to provide only amplitude control of the current through the LED. While many of the embodiments provided herein describe the use of PWM and PAM to drive the LEDs, one skilled in the art would appreciate that there are many techniques to accomplish the LED control described herein and, as such, the scope of the present invention is not limited by any one control technique. In embodiments, it is possible to use other techniques, such as pulse frequency modulation (PFM), or pulse displacement modulation (PDM), such as in combination with either or both of PWM and PAM.

Pulse width modulation (PWM) involves supplying a substantially constant current to the LEDs for particular periods of time. The shorter the time, or pulse-width, the less brightness an observer will observe in the resulting light. The human eye integrates the light it receives over a period of time and, even though the current through

the LED may generate the same light level regardless of pulse duration, the eye will perceive short pulses as "dimmer" than longer pulses. The PWM technique is considered on of the preferred techniques for driving LEDs, although the present invention is not limited to such control techniques. When two or more colored LEDs are provided in a lighting system, the colors may be mixed and many variations of colors can be generated by changing the intensity, or perceived intensity, of the LEDs. In an embodiment, three colors of LEDs are presented (e.g., red, green and blue) and each of the colors is driven with PWM to vary its apparent intensity. This system allows for the generation of millions of colors (e.g., 16.7 million colors when 8-bit control is used on each of the PWM channels).

In an embodiment the LEDs are modulated with PWM as well as modulating the amplitude of the current driving the LEDs (Pulse Amplitude Modulation, or PAM). LED efficiency as a function of the input current increases to a maximum followed by decreasing efficiency. Typically, LEDs are driven at a current level beyond maximum efficiency to attain greater brightness while maintaining acceptable life expectancy. The objective is typically to maximize the light output from the LED while maintaining an acceptable lifetime. In an embodiment, the LEDs may be driven with a lower current maximum when lower intensities are desired. PWM may still be used, but the maximum current intensity may also be varied depending on the desired light output. For example, to decrease the intensity of the light output from a maximum operational point, the amplitude of the current may be decreased until the maximum efficiency is achieved. If further reductions in the LED brightness are desired the PWM activation may be reduced to reduce the apparent brightness.

One issue that may arise in connection with controlling multiple light sources 300 in the lighting unit 102, and controlling multiple lighting units 102 in a lighting system relates to potentially perceptible differences in light output between substantially similar light sources. For example, given two virtually identical light sources being driven by respective identical control signals, the actual intensity of light output by each light source may be perceptibly different. Such a difference in light output may be attributed

to various factors including, for example, slight manufacturing differences between the light sources, normal wear and tear over time of the light sources that may differently alter the respective spectrums of the generated radiation, etc. For purposes of the present discussion, light sources for which a particular relationship between a control signal and resulting intensity are not known are referred to as "uncalibrated" light sources.

The use of one or more uncalibrated light sources in the lighting unit 102 may result in generation of light having an unpredictable, or "uncalibrated," color or color temperature. For example, consider a first lighting unit including a first uncalibrated red light source and a first uncalibrated blue light source, each controlled by a corresponding control signal having an adjustable parameter in a range of from zero to 255 (0-255). For purposes of this example, if the red control signal is set to zero, blue light is generated, whereas if the blue control signal is set to zero, red light is generated. However, if both control signals are varied from non-zero values, a variety of perceptibly different colors may be produced (e.g., in this example, at very least, many different shades of purple are possible). In particular, perhaps a particular desired color (e.g., lavender) is given by a red control signal having a value of 125 and a blue control signal having a value of 200.

Now consider a second lighting unit including a second uncalibrated red light source substantially similar to the first uncalibrated red light source of the first lighting unit, and a second uncalibrated blue light source substantially similar to the first uncalibrated blue light source of the first lighting unit. As discussed above, even if both of the uncalibrated red light sources are driven by respective identical control signals, the actual intensity of light output by each red light source may be perceptibly different. Similarly, even if both of the uncalibrated blue light sources are driven by respective identical control signals, the actual intensity of light output by each blue light source may be perceptibly different.

With the foregoing in mind, it should be appreciated that if multiple uncalibrated light sources are used in combination in lighting units to produce a mixed colored light as discussed above, the observed color (or color temperature) of light produced by

different lighting units under identical control conditions may be perceivably different. Specifically, consider again the "lavender" example above; the "first lavender" produced by the first lighting unit with a red control signal of 125 and a blue control signal of 200 indeed may be perceptibly different than a "second lavender" produced by the second lighting unit with a red control signal of 125 and a blue control signal of 200. More generally, the first and second lighting units generate uncalibrated colors by virtue of their uncalibrated light sources.

In view of the foregoing , in one embodiment of the present invention, the lighting unit 102 includes a calibration facility to facilitate the generation of light having a calibrated (e.g., predictable, reproducible) color at any given time. In one aspect, the calibration facility is configured to adjust the light output of at least some light sources of the lighting unit so as to compensate for perceptible differences between similar light sources used in different lighting units.

For example, in one embodiment, the processor 3600 of the lighting unit 102 is configured to control one or more of the light sources 300 so as to output radiation at a calibrated intensity that substantially corresponds in a predetermined manner to a control signal for the light source(s). As a result of mixing radiation having different spectra and respective calibrated intensities, a calibrated color is produced. In one aspect of this embodiment, at least one calibration value for each light source is stored in the data facility 3700, and the processor 3600 is programmed to apply the respective calibration values to the control signals for the corresponding light sources so as to generate the calibrated intensities.

In one aspect of this embodiment, one or more calibration values may be determined once (e.g., during a lighting unit manufacturing/testing phase) and stored in memory 3700 for use by the processor 3600. In another aspect, the processor 3600 may be configured to derive one or more calibration values dynamically (e.g. from time to time) with the aid of one or more photosensors, for example. In various embodiments, the photosensor(s) may be one or more external components coupled to the lighting unit,

or alternatively may be integrated as part of the lighting unit itself. A photosensor is one example of a signal source that may be integrated or otherwise associated with the lighting unit 102, and monitored by the processor 3600 in connection with the operation of the lighting unit. Other examples of such signal sources are discussed further below, in connection with the signal source 8400.

One exemplary method that may be implemented by the processor 3600 to derive one or more calibration values includes applying a reference control signal to a light source, and measuring (e.g., via one or more photosensors) an intensity of radiation thus generated by the light source. The processor may be programmed to then make a comparison of the measured intensity and at least one reference value (e.g., representing an intensity that nominally would be expected in response to the reference control signal). Based on such a comparison, the processor may determine one or more calibration values for the light source. In particular, the processor may derive a calibration value such that, when applied to the reference control signal, the light source outputs radiation having an intensity that corresponds to the reference value (i.e., the "expected" intensity).

In various aspects, one calibration value may be derived for an entire range of control signal/output intensities for a given light source. Alternatively, multiple calibration values may be derived for a given light source (i.e., a number of calibration value "samples" may be obtained) that are respectively applied over different control signal/output intensity ranges, to approximate a nonlinear calibration function in a piecewise linear manner.

Referring to Fig. 25c, typically an LED produces a narrow emission spectrum centered on a particular wavelength; i.e. a fixed color. Through the use of multiple LEDs and additive color mixing a variety of apparent colors can be produced, as described elsewhere herein.

In conventional LED-based light systems, constant current control is often preferred because of lifetime issues. Too much current can destroy an LED or curtail

useful life. Too little current produces little light and is an inefficient or ineffective use of the LED.

The light output from a semiconductor illuminator may shift in wavelength as a result in changes in current. In general, the shift in output has been thought to be undesirable for most applications, since a stable light color is often preferred to an unstable one. Recent developments in LED light sources with higher power ratings (>100mA) have made it possible to operate LED systems effectively without supplying maximum current. Such operational ranges make it possible to provide LED-based lighting units 102 that have varying wavelength outputs as a function of current. Thus, different wavelengths of light can be provided by changing the current supplied to the LEDs to produce broader bandwidth colors (potentially covering an area, rather than just a point, in the chromaticity diagram of Fig. 26), and to produce improved quality white light. This calibration technique not only changes the apparent intensity of the LEDs (reflecting the portion of the duty cycle of a pulse width modulation signal during which the LED is on as compared to the portion during which it is off), but also shifting the output wavelength or color. Current change can also broaden the narrow emission of the source, shifting the saturation of the light source towards a broader spectrum source. Thus, current control of LEDs allows controlled shift of wavelength for both control and calibration purposes.

In the visible spectrum, roughly 400 to 700nm, the sensitivity of the eye varies according to wavelength. The sensitivity of the eye is least at the edges of that range and peaks at around 555nm in the middle of the green.

Referring to Fig. 25b, a schematic diagram shows pulse shapes for a PWM signal. By rapidly changing the current and simultaneously adjusting the intensity via PWM, a broader spectrum light source can be produced. Fig. 25b shows two PWM signals. The two PWM signals vary both in current level and width. The top one has a narrower pulse-width, but a higher current level than the bottom one. The result is that the narrower pulse offsets the increased current level in the top signal. As a result,

depending on the adjustment of the two factors (on-time and current level) both light outputs could appear to be of similar brightness. The control is a balance between current level and the on time. Fig. 25a shows an embodiment of a drive facility 3800 for simultaneous current control and on-off control under the control of a processor 3600.

Controlled spectral shifting can also be used to adjust for differences between light sources 300, such as differences between individual light sources 300 from the same vendor, or different lots, or "bins," of light sources 300 from different vendors, such as to produce lighting units 102 that produce consistent color and intensity from unit to unit, notwithstanding the use of different kinds of light sources 300 in the respective lighting units 102.

Fig. 25c shows the effect of changing both the current and adjusting the PWM for the purposes of creating a better quality white by shifting current and pulse-widths simultaneously and then mixing multiple sources, such as RG & B, to produce a high quality white. The spectrum is built up by rapidly controlling the current and on-times to produce multiple shifted spectra. Thus, the original spectrum is shifted to a broader-spectrum by current shifts, while coordinated control of intensity is augmented by changes in PWM.

Current control can be provided with various embodiments, including feedback loops, such as using a light sensor as a signal source 8400, or a lookup table or similar facility that stores light wavelength and intensity output as a function of various combinations of pulse-width modulation and pulse amplitude modulation.

In embodiments, a lighting system can produce saturated colors for one purpose (entertainment, mood, effects), while for another purpose it can produce a good quality variable white light whose color temperature can be varied along with the spectral properties. Thus a single fixture can have narrow bandwidth light sources for multicolor light applications and then can change to a current and PWM control mode to get broad spectra to make good white light or non-white light with broader spectrum color

characteristics. In addition, the control mode can be combined with various optical facilities 400 described above to further control the light output from the system. In embodiments, the methods and systems can include a control loop and fast current sources to allow an operator to sweep about a broad spectrum. This could be done in a feed-forward system or with feedback to insure proper operation over a variety of conditions.

The control facility 3500 can switch between a current-control mode 2502 (which itself could be controlled by a PWM stream) and a separate PWM mode 2504. Such a system can include simultaneous current control via PWM for wavelength and PWM control balanced to produce desired output intensity and color. Fig. 25a shows a schematic diagram with one possible embodiment for creating the two control signals from a controller, such as a microprocessor to control one or more LEDs in a string. Multiple such strings can be used to create a light fixture that can vary in color (HSB) and spectrum based on the current and on-off control. The PWM signal can also be a PWM Digital-to-analog converter (DAC) such as those from Maxim and others. Note that the functions that correspond to particular values of output can be calibrated ahead of time by determining nominal values for the PWM signals and the resultant variations in the LED output. These can be stored in lookup tables or a function created that allows the mapping of desired values from LED control signals.

It may even be desirable to overdrive the LEDs. Although the currents would be above nominal operating parameters as described by the LED manufacturers, this can provide more light than normally feasible. The power source will also be drained faster, but the result can be a much brighter light source.

Modulation of lighting units 102 can include a data facility 3700, such as a look-up table, that determines the current delivered to light sources 300 based on predetermined values stored in the data facility 3700 based on inputs, which may include inputs from signal sources 8400, sensors, or the like.

It is also possible to drive light sources 300 with constant current, such as to produce a single color of light.

The methods and systems disclosed herein also include a variety of methods and systems for light control, including central control facilities 3500 as well as control facilities that are local to lighting units 102. One grouping of control facilities 3500 includes dimmer controls, including both wired and wireless dimmer control. Traditional dimmers can be used with lighting units 102, not just in the traditional way using voltage control or resistive load, but rather by using a processor to scale and control output by interpreting the levels of voltage. In combination with a style and interface that is familiar to most people because of the ubiquity of dimmer switches, one aspect of the present specification allows the position of a dimmer switch (linear or rotary) to indicate color temperature or intensity through a power cycle control. That is, the mode can change with each on or off cycle. A special switch can allow multiple modes without having to turn off the lights. An example of a product that uses this technique is the Color Dial, available from Color Kinetics.

Referring to Fig. 26, a chromaticity diagram shows a range of colors that can be viewed by the human eye. The gamut 2614 defines the range of colors that it is possible to produce by additively mixing colors from multiple sources, such as three LEDs. Green LEDs produce light in a green region 2612, red LEDs produce light in a red region 2618 and blue LEDs produce light in a blue region 2620. Mixing these colors produces mixed light output, such as in the overlapping areas between the regions, including those for orange, purple and other mixed light colors. Mixing all three sources produces white light, such as along a black body curve 1310. Different mixtures produce different color temperatures of white light along or near the black body curve 2610. Typically an LED produces a narrow emission spectrum centered on a particular wavelength; i.e. a fixed color and a single point on the chromaticity diagram. Through the use of multiple LEDs and additive color mixing a variety of apparent colors can be produced. In embodiments the gamut 2614 may be determined by a program stored on the data storage facility 3700, rather than by the light output capacities of light sources 300. For example, a more